CSE 559A: Computer Vision

[credit: danjodon.deviantart.com]

Fall 2017: T-R: 11:30-1pm @ Lopata 101

Instructor: Ayan Chakrabarti (ayan@wustl.edu).
Staff: Abby Stylianou (abby@wustl.edu), Jarett Gross (jarett@wustl.edu)

http://www.cse.wustl.edu/~ayan/courses/cse559a/

Sep 19, 2017

ADMINISTRIVIA

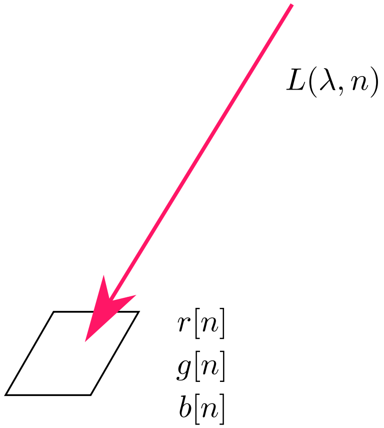
- Recitation will be this Friday (9/22) in J309.
  - Will go over topics relevant to Pset.
- Yesterday office hours canceled last minute
  - Q: Useful to have another set this week ?

GENERAL

Suggestions about Pset

- Look at the support code !
- Look at math / coding resources on course website
- Problem 3:
  - Direction of θ depends on convention. NMS fig in lecture slides is just an example.
  - Any convention is correct, as long as it is internally consistent.
  - LOOK at the results and see if your code is doing the right thing !
  - The idea is that you should 'thin' edges to select maxima.
- Problem 4:
  - Support code calls bilateral filter multiple times deliberately
    (to encourage you to write efficient code!)
  - If you want to debug, temporary comment out later calls (or just press ctrl+c after first file saved).

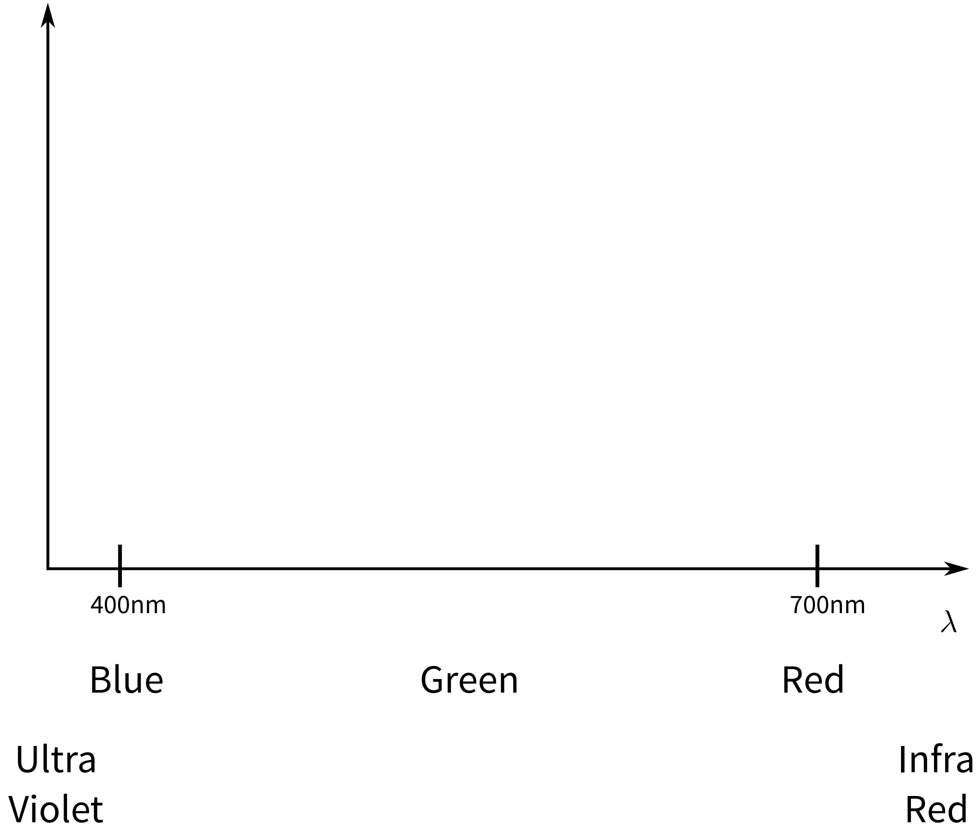
COLOR



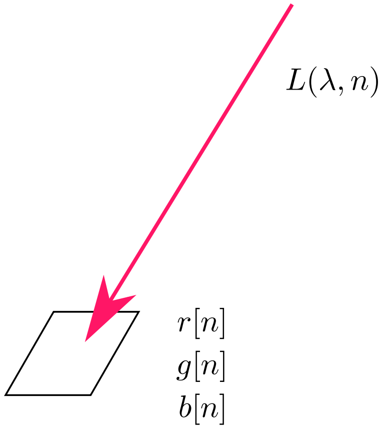
$$r[n] = \int L(\lambda, n)\Pi_r(\lambda)d\lambda$$

$$g[n] = \int L(\lambda, n)\Pi_g(\lambda)d\lambda$$

$$b[n] = \int L(\lambda, n)\Pi_b(\lambda)d\lambda$$



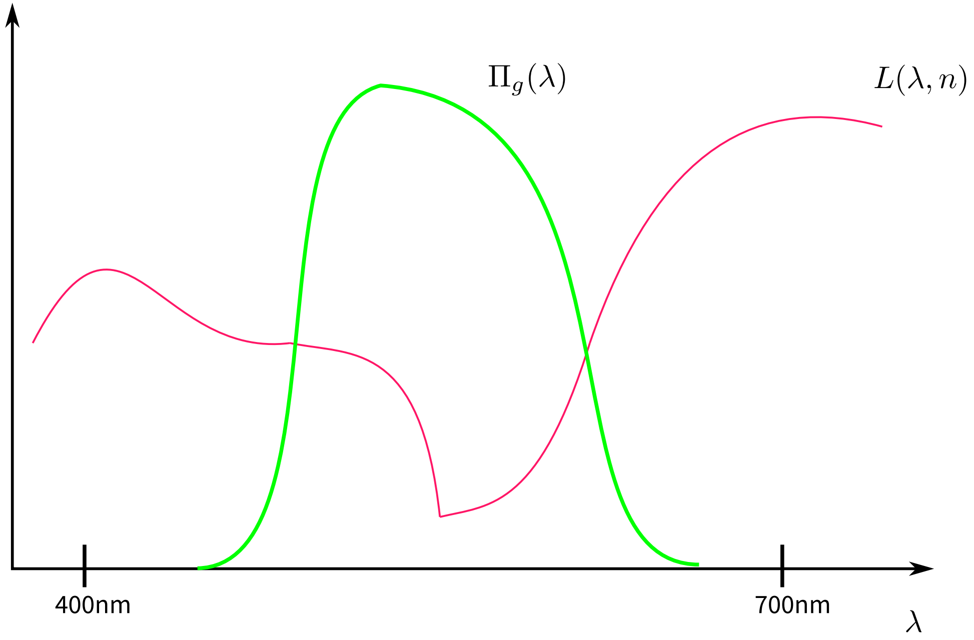
COLOR



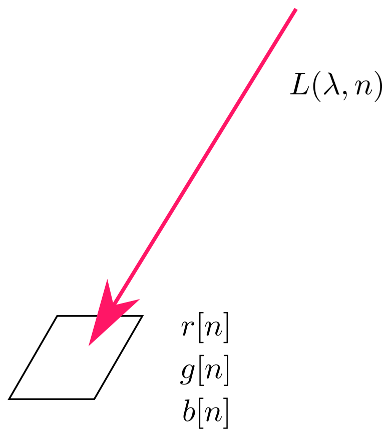
$$r[n] = \int L(\lambda, n)\Pi_r(\lambda)d\lambda$$

$$\boxed{g[n] = \int L(\lambda, n)\Pi_g(\lambda)d\lambda}$$

$$b[n] = \int L(\lambda, n)\Pi_b(\lambda)d\lambda$$



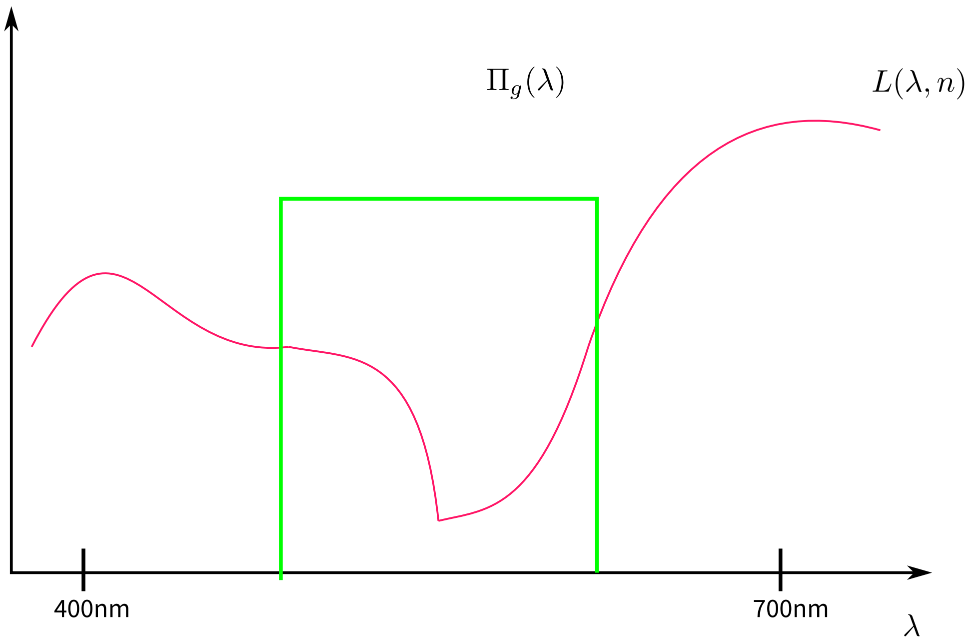
COLOR



$$r[n] = \int L(\lambda, n)\Pi_r(\lambda)d\lambda$$

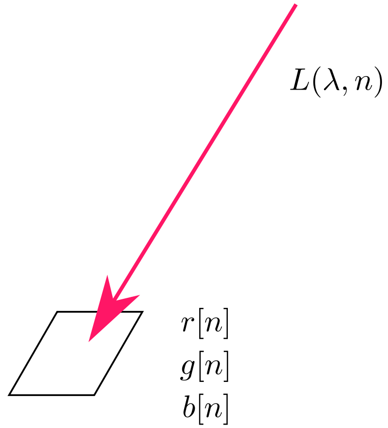
$$\boxed{g[n] = \int L(\lambda, n)\Pi_g(\lambda)d\lambda}$$

$$b[n] = \int L(\lambda, n)\Pi_b(\lambda)d\lambda$$



Simple View:
Total / Average Intensity in "Green Part" of the spectrum.

COLOR

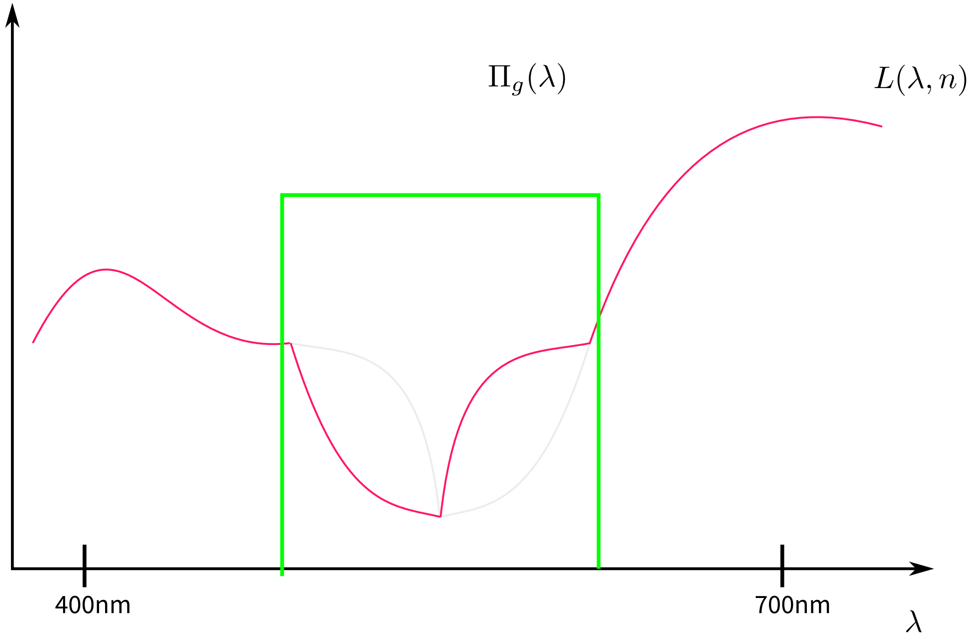


$$r[n] = \int L(\lambda, n)\Pi_r(\lambda)d\lambda$$

$$\boxed{g[n] = \int L(\lambda, n)\Pi_g(\lambda)d\lambda}$$

$$b[n] = \int L(\lambda, n)\Pi_b(\lambda)d\lambda$$

Metamers: Different L that have the same measured RGB values.



Simple View:

Total / Average Intensity in "Green Part" of the spectrum.

COLOR

For simplicity,

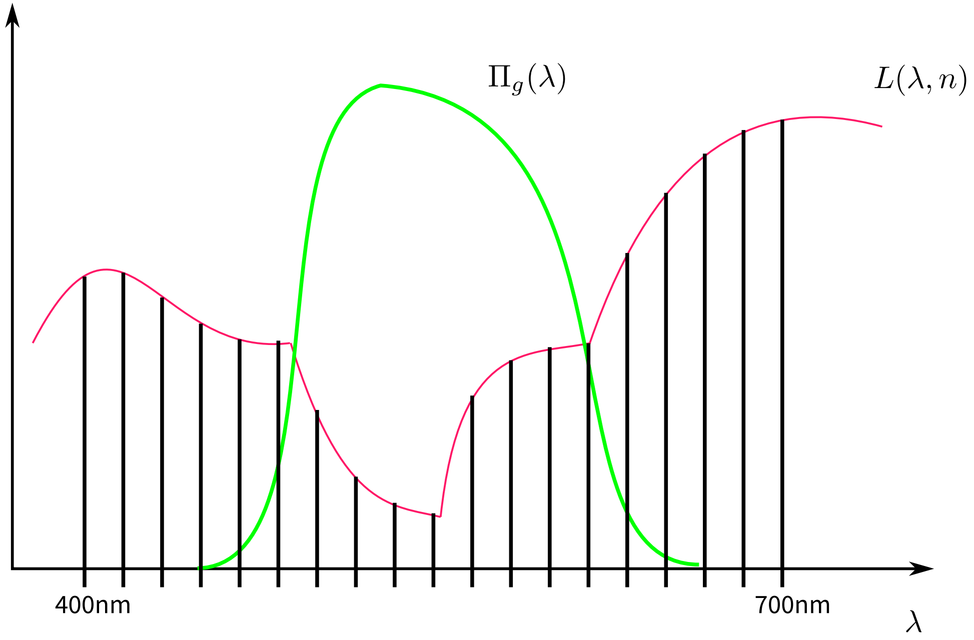
Have discrete wavelengths

Approximate integration as summation

$$r[n] = \int L(\lambda, n)\Pi_r(\lambda)d\lambda$$

$$g[n] = \int L(\lambda, n)\Pi_g(\lambda)d\lambda$$

$$b[n] = \int L(\lambda, n)\Pi_b(\lambda)d\lambda$$



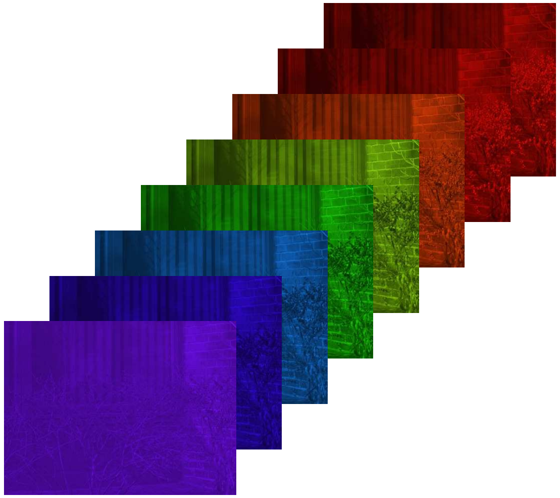
$$L(\lambda, n) \rightarrow L[\lambda, n] \text{ or } L[n] \in \mathbb{R}^B$$

COLOR

$$r[n] = \langle L[n], \Pi_r \rangle$$

$$g[n] = \langle L[n], \Pi_g \rangle$$

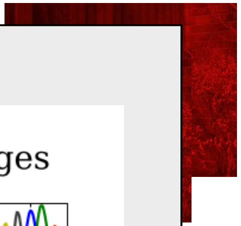
$$b[n] = \langle L[n], \Pi_b \rangle$$

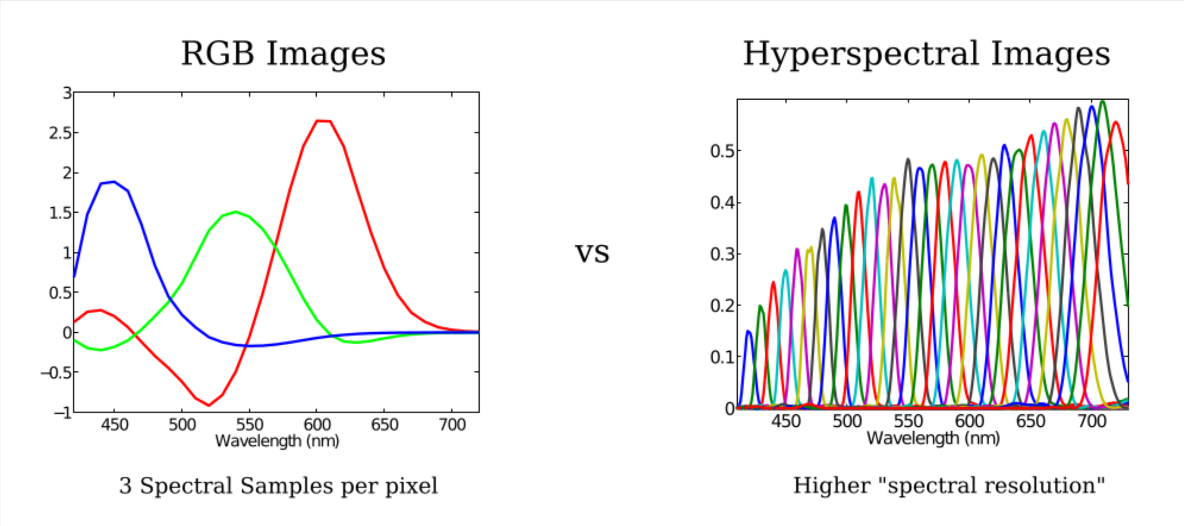


Think of the incident light being
a B (>> 3) channel image $L[n]$

$$L(\lambda, n) \rightarrow L[\lambda, n] \text{ or } L[n] \in \mathbb{R}^B$$

COLOR





$X[n]$

I

There are cameras that actually capture such "hyperspectral" images.

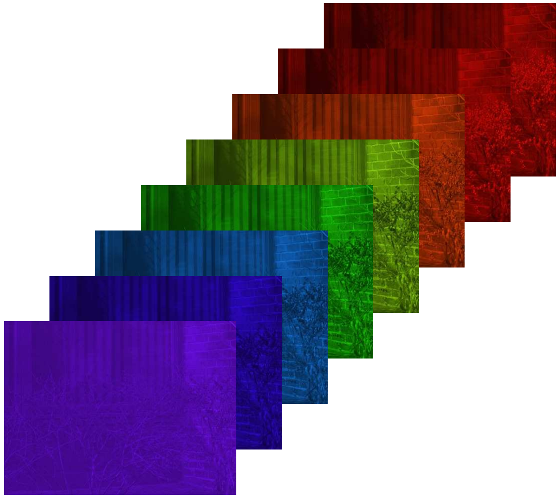
$L(\lambda, n) \rightarrow L[\lambda, n]$ or $L[n] \in \mathbb{R}^B$

COLOR

$$X[n] = \Pi^T \; L[n],$$

$$\Pi = [\Pi_r \quad \Pi_g \quad \Pi_b]$$

(B x 3 Matrix)



Think of the incident light being a B (>> 3) channel image $L[n]$

- 3 Dimensional Projection from higher dimensional space

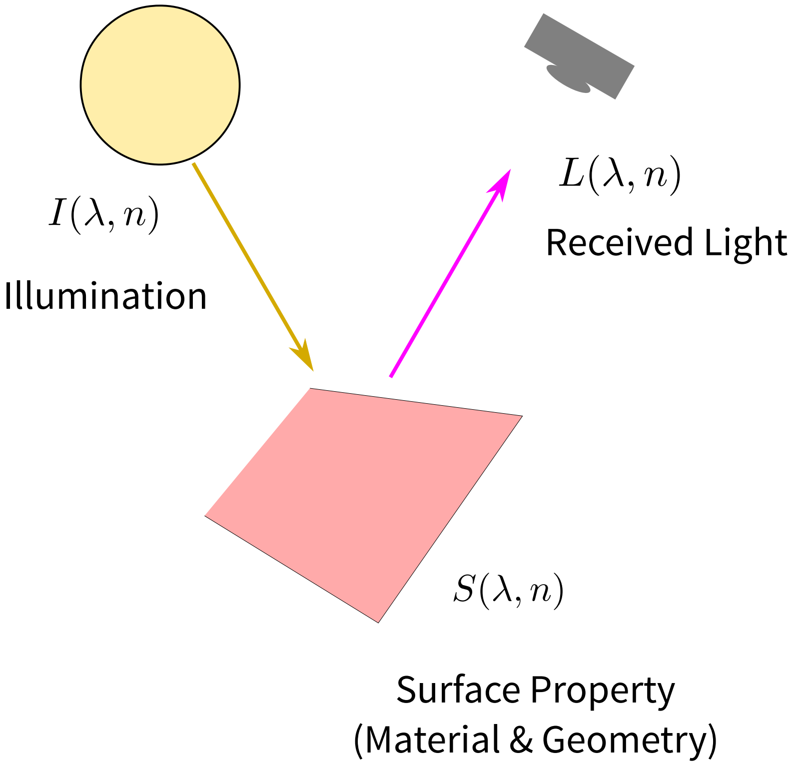
- Invariant to changes in the "null space" of Π

COLOR

Light Color vs Object Color

COLOR

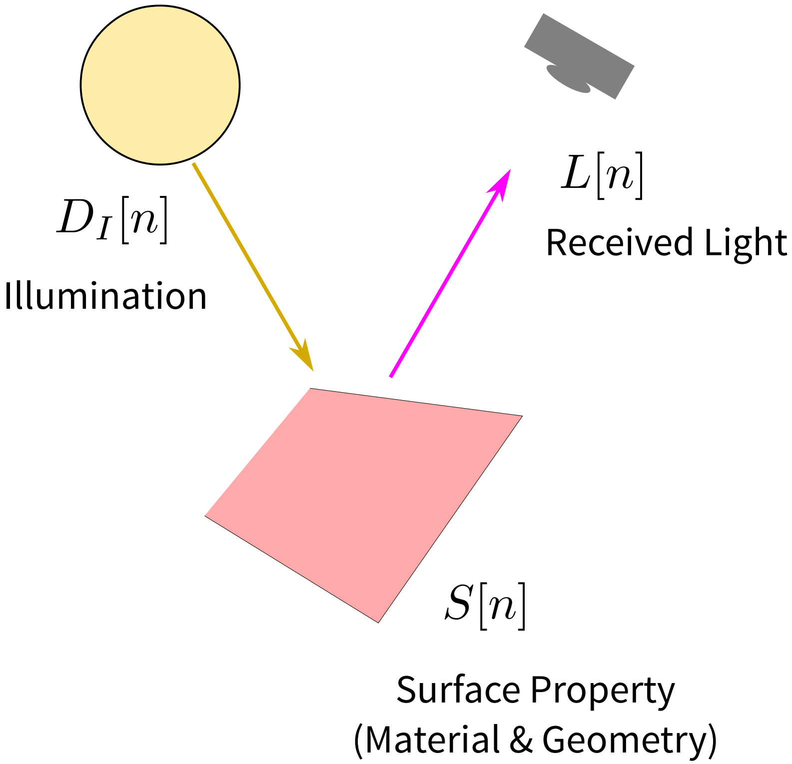
Light Color vs Object Color



$$L(\lambda, n) = S(\lambda, n) \quad I(\lambda, n)$$

COLOR

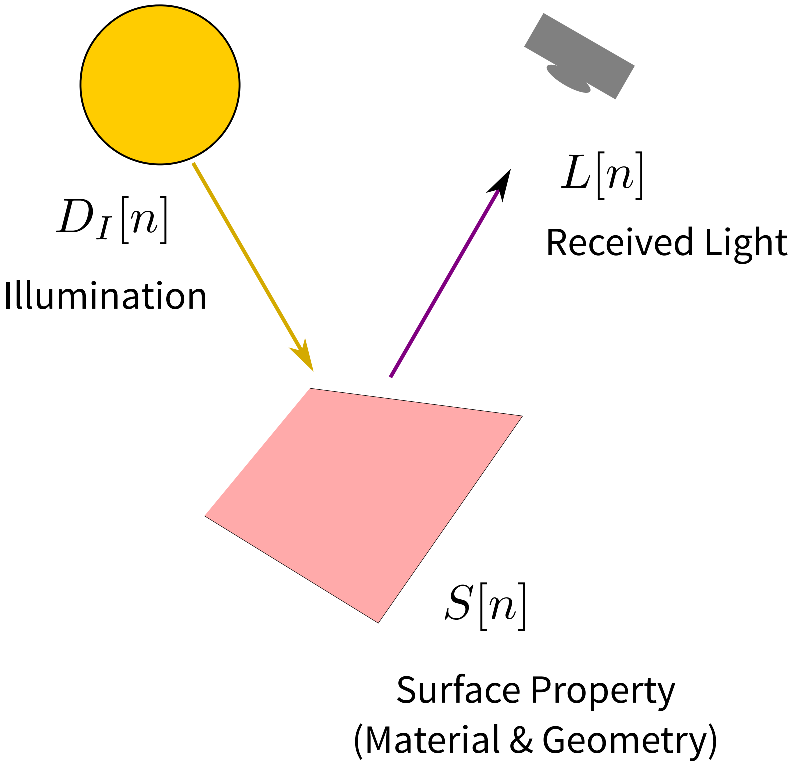
Light Color vs Object Color



$$L[n] \;=\; D_I[n] \;\; S[n]$$

COLOR

Light Color vs Object Color



$$L[n] = D_I[n] \; S[n]$$

Why is this important ?

Because observed color can change with illuminant color.

COLOR

Light Color vs Object Color

$$L[n] \;=\; D_I[n] \;\; S[n]$$

Why is this important ?

Because observed color can change with illuminant color.

COLOR

Quick Aside: Color Temperature

Natural Illuminants often well-modeled as "black body radiators" at different "temperatures"

$$I(\lambda) \propto \frac{1}{\lambda^5} \frac{1}{\exp(\frac{hc}{k\lambda T}) - 1}$$

h is Planck's constant, k is Boltzmann's constant, and
T is "color temperature"

Warmer / cooler colors = Colors observed under illuminants with higher / lower temperature T

COLOR

Light Color vs Object Color

$$X_1[n] = \Pi^T \left(D_{I_1}[n] S[n]\right)$$

$$L[n] \quad = \quad D_I[n] \quad S[n]$$

$$X[n] = \Pi^T L[n]$$

$$X_2[n] = \Pi^T \left(D_{I_2}[n] S[n]\right)$$

COLOR

Light Color vs Object Color

$$X_1[n] = \Pi^T \left(D_{I_1}[n] S[n]\right)$$

Even if you knew I_1 and I_2,
could you go from X_1 to X_2 ?

NO

$$X_2[n] = \Pi^T \left(D_{I_2}[n] S[n]\right)$$

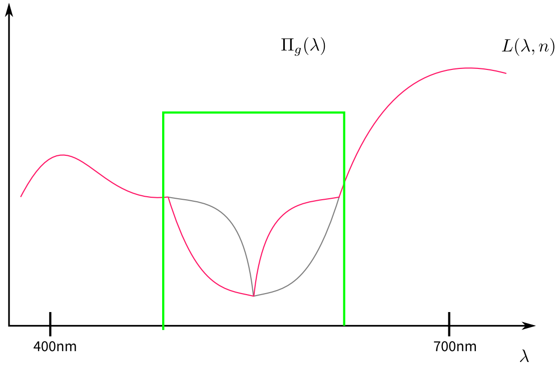
COLOR

Light Color vs Object Color

$$X_1[n] = \Pi^T \left(D_{I_1}[n] S[n] \right)$$

Possible for two distinct values of S to go to same RGB value of X under I_1 but **not** I_2.

$$X_2[n] = \Pi^T \left(D_{I_2}[n] S[n] \right)$$



COLOR

Light Color vs Object Color

Chong, Gortler, and Zickler, "The von Kries Hypothesis and a Basis for Color Constancy", ICCV 2007

$$X_1[n] = \Pi^T \left(D_{I_1}[n] S[n]\right)$$

Approximations:

- Ver 1: $X_1[n] = C_{2\to 1} X_2[n]$ — Linear Transform

$$X_1[n] = C D_{2\to 1} C^T X_2[n]$$

Diagonal Transform in some color space (doesn't depend on 1,2)

- Ver 2: $X_1[n] = D_{2\to 1} X_2[n]$ — Diagonal Transform "von-Kries" model

$$X_2[n] = \Pi^T \left(D_{I_2}[n] S[n]\right)$$

COLOR

Light Color vs Object Color

$$X_1[n] = \Pi^T \left(D_{I_1}[n] S[n]\right)$$

$$X_1[n] = D_{2\to 1} X_2[n]$$

But this is only if we know the illuminants I_1 and I_2.

Looking at an image and separating illuminant and surface colors: color constancy

$$X_2[n] = \Pi^T \left(D_{I_2}[n] S[n]\right)$$

COLOR

Color Constancy

$$X_1[n] = \Pi^T \left(D_{I_1} \quad S[n] \right)$$

- Assume single (or dominant) illuminant for the scene

- Say illuminant I_1 is some known "canonical illuminant"

- Our task is, given $X_2[n]$ under unknown illumination I_2, to go to an image of the scene under the canonical illuminant.

$$X_1[n] = \underline{D_{2\rightarrow 1}} X_2[n]$$

Estimate Transform

$$X_2[n] = \Pi^T \left(D_{I_2} \quad S[n] \right)$$

- Color constancy is about removing color cast, not say 'brightness'.
- Need to estimate transform upto scale, e.g., assume elements add upto 3

COLOR

Color Constancy

$$X_1[n] = \begin{bmatrix} d_r & & \\ & d_g & \\ & & d_b \end{bmatrix} X_2[n]$$

- Have a prior on natural colors (under canonical illumination)

- Find transform so that colors in X_1 match the prior

Prior 1: Gray World
- On average, colors are neutral or gray

$$d_r \propto \frac{1}{\text{Mean}_n(X_2^r[n])}$$

Fails if there's a dominant color in the scene (like lots of grass)

COLOR

Color Constancy

$$X_1[n] = \begin{bmatrix} d_r & & \\ & d_g & \\ & & d_b \end{bmatrix} X_2[n]$$

- Have a prior on natural colors (under canonical illumination)

- Find transform so that colors in X_1 match the prior

Prior 2: White Patch Retinex

- The brightest color is neutral (or white)

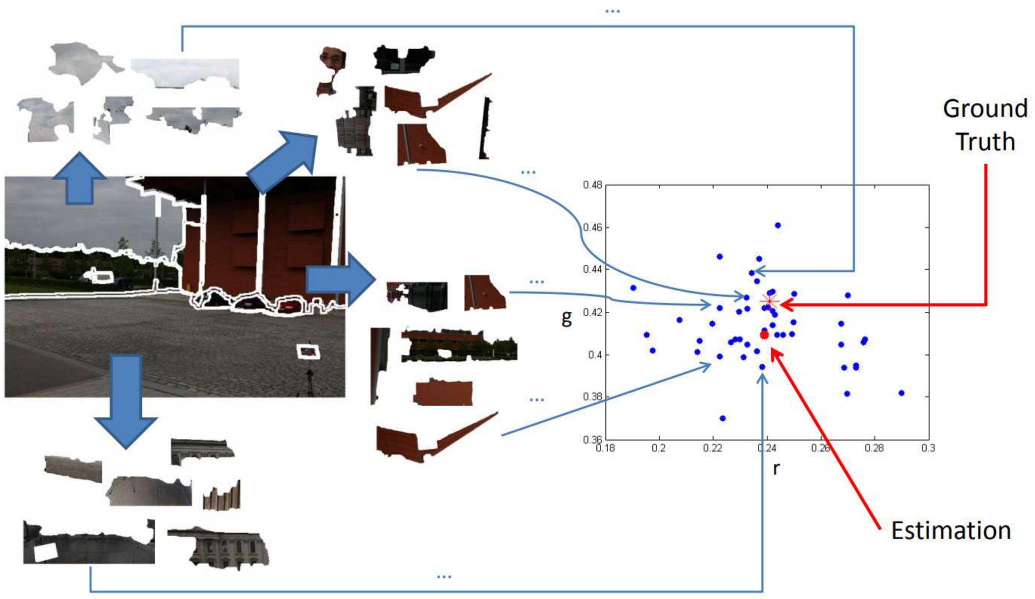
$$d_r \propto \frac{1}{\mathrm{Max}_n(X_2^r[n])}$$

Probably want to average over the highest k values instead of just max.

COLOR

Color Constancy

- Remains an active area of research. Modern methods include using CNNs, trying to match objects, and so on.



Joze & Drew, Exemplar-based Color Constancy and Multiple Illumination, PAMI 2014

COLOR

Color Constancy

- Remains an active area of research. Modern methods include using CNNs, trying to match objects, and so on.

- Humans solve it well, but vision scientists still trying to figure out how

COLOR

Color Constancy

- Remains an active area of research. Modern methods include using CNNs, trying to match objects, and so on.

- Humans solve it well, but vision scientists still trying to figure out how

- Multi-illuminant case even more interesting. Efforts to solve it with more information.

(a) No-flash / flash images (b) Lighting separation (c) White-balance (d) Light editing

Hui et al., Post-Capture Lighting Manipulation using Flash Photography, arXiv 1704.05564

COLOR

Color Representation / Spaces

- We're using 3 numbers to represent color: co-ordinates in some space.

- But RGB may not always be the right way to "work" with color.

- The right representation depends on what you're trying to do:

  - Analyze an Image
  - Restore a degraded Image
  - Manipulate an Image for Visual / Artistic Quality
  - Print / Display Images
  - Measure similarity between two images

COLOR

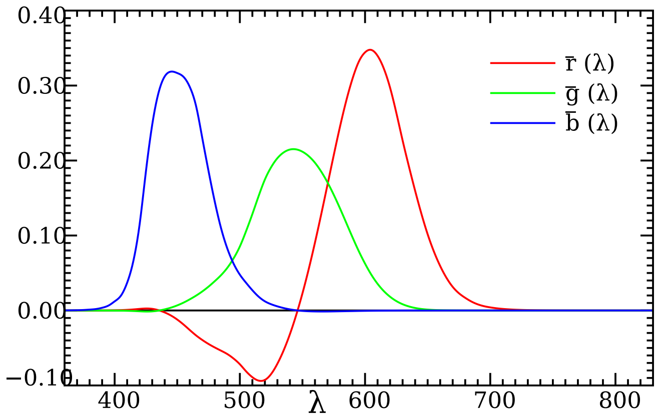
Color Representation / Spaces

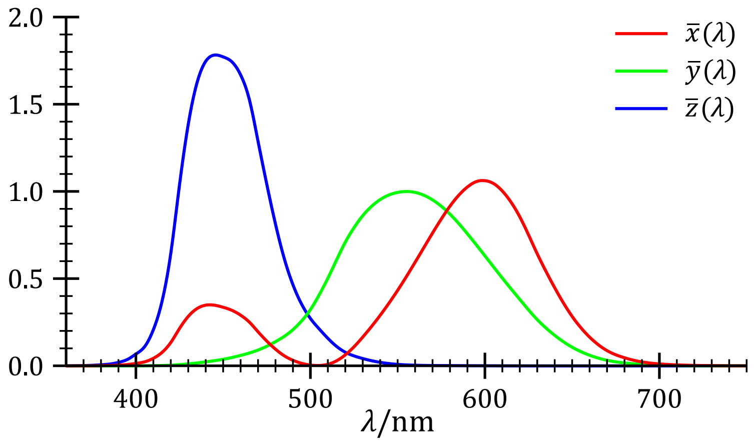
Linear Spaces: Some linear transformation of RGB

$$X_{ABC} = T \quad X_{RGB}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.418{,}47 & -0.158{,}66 & -0.082{,}835 \\ -0.091{,}169 & 0.252{,}43 & 0.015{,}708 \\ 0.000{,}920{,}90 & -0.002{,}549{,}8 & 0.178{,}60 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

- **XYZ**: This is a CIE standard, because the RGB filter functions are actually negative !





Source: Wikipedia

COLOR

Color Representation / Spaces

Linear Spaces: Some linear transformation of RGB

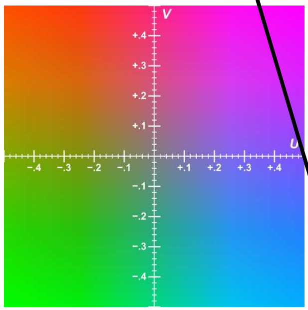
$$X_{ABC} = T \quad X_{RGB}$$

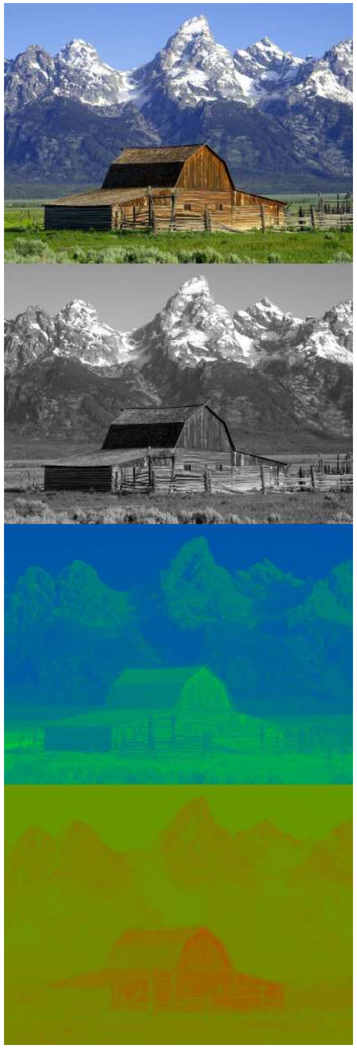
May be useful to process these independently (instead of R,G,B)

- YUV: Useful as a "decorrelating" transform.

$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix},$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y' \\ U \\ V \end{bmatrix}.$$





Think of Y as grayscale image.
Called luma, luminance, lightness

U and V is the "color information"

COLOR

Color Representation / Spaces

Non-Linear Transforms

Lightness and rg Chromaticity

$$L = (R + G + B), r = R/L, g = G/L$$

Could also do this in XYZ (xy-chromaticity).
Main idea is that we're representing colors as ratios, instead of linear transform.
Chromaticity values stay constant with changing brightness, UV values don't.

Input

Y / L

Histogram Equalized

Keep U,V from original image

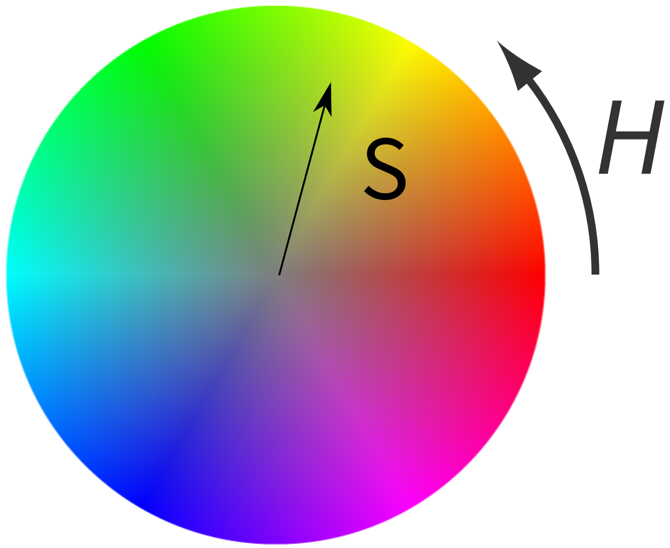
Keep r,g from original image

COLOR

Color Representation / Spaces

Non-Linear Transforms

Other ways of representing chromaticity: Hue/Saturation

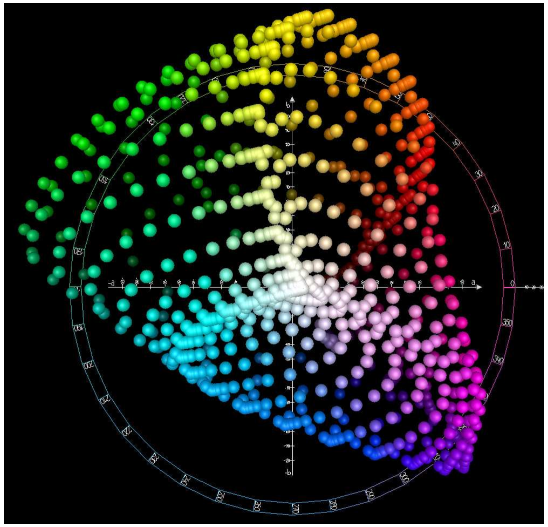


COLOR

Color Representation / Spaces

Non-Linear Transforms

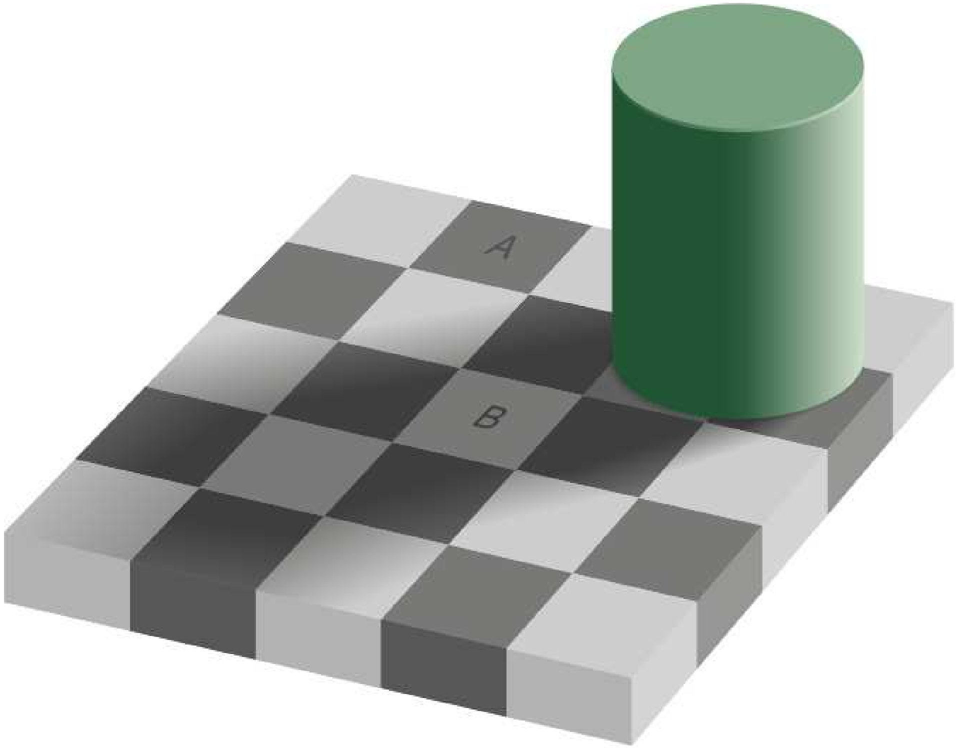
CIE LAB color space: Distances in Lab are "perceptually meaningful"



Read: Wikipedia Article on CIE-LAB for exact definition.

SHADING

Observed color isn't the only thing that changes with the environment. So does lightness.

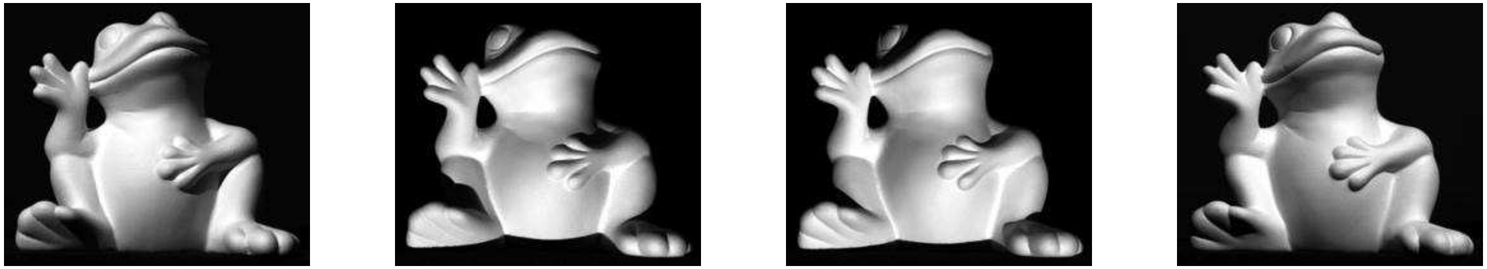


Squares A and B have exactly the same intensity.

But we don't just want brightness constancy !

Source: Ted Edelson

SHADING

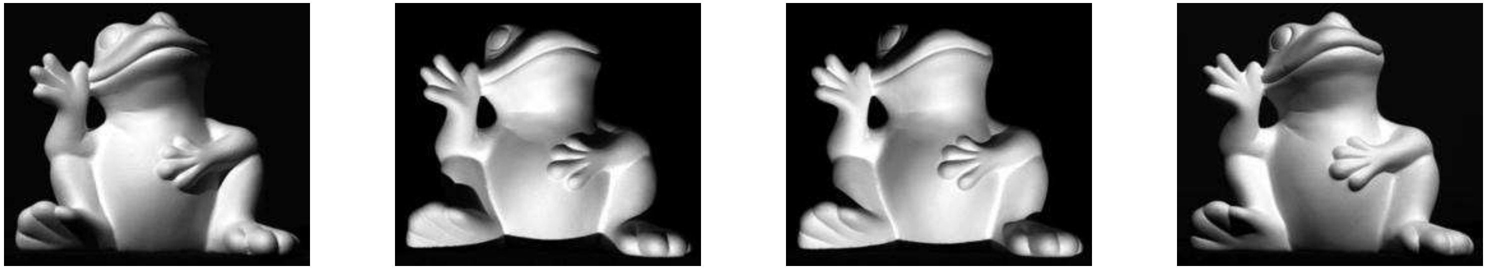


The way intensity changes over a constant surface, in a single image, or with change in lighting, can be a strong cue for shape.

Source: Belhumeur, Kriegman, and Yuille

Sculptors have used it to fake depth.

SHADING



The way intensity changes over a constant surface, in a single image, or with change in lighting, can be a strong cue for shape.

Source: Debevec

Computer Vision has used it for shape capture

SHADING

Shading can be quite complex, depending on the material !